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SUN OIL CO MARCUS HOOK PA APPLIED RESEARCH AND DEVEL--ETC F/G 11/8
INFRARED SPECTRA OF FLUID FILMS UNDER CONDITIONS OF INCIPIENT B--ETC(U)
1976 J L LAUER F44620-74-C-0038

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REPORT DOCUMENTATION PAGE		INSTRUCTIONS COMPLETING FORM
1. REPORT NUMBER AFOSR - TR - 77 - 0182	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) INFRARED SPECTRA OF FLUID FILMS UNDER CONDITIONS OF INCIPIENT BEARING FAILURE, PHASE I.		5. TYPE OF REPORT & PERIOD COVERED Final, 1 Jan 74 - 30 Jun 76
7. AUTHOR(s) James L. Lauer		8. CONTRACT OR GRANT NUMBER(s) F44620-74-C-0038
9. PERFORMING ORGANIZATION NAME AND ADDRESS Applied Research and Development Dept. Sun Oil Co., PO Box 1135 Marcus Hook, Pa. 19061		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 9536-02, 61102F
11. CONTROLLING OFFICE NAME AND ADDRESS AF Office of Scientific Research/NC Bolling AFB, Bldg. 410 Washington, DC 20332		12. REPORT DATE 1976
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES 4
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		15. SECURITY CLASS. (of this report) Unclassified
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report) Final rpt. 1 Jan 74 - 30 Jun 76		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A novel method of analysis using infrared emission Fourier Transform Spectro- photometry was developed to study lubricant behavior under conditions of incipient bearing failure. Objectives of the research were (i) to demonstrate that infrared emission spectrophotometry can be applied to bearing contact situations, (ii) to provide background in the form of calibration spectra applicable to such situations, and (iii) to show the potential of the method in specific instances relevant to the failure problem. A high-pressure diamond anvil cell was used as a "simulated		

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contact." Its sample volume could be subjected to most of the conditions likely to prevail in a sliding EHD Hertzian contact thickness less than 2 micro meters, open area approximately 0.25 mm², pressures 0-75 kbar, temperatures 0-200°C) except for shear. As typical fluids, an ester, polyphenyl ether (5P4E), a standard petroleum lubricant, and a so-called "traction" fluid were used. A Fourier infrared interferometer was adapted for all the spectroscopic work. In the initial stages of the program, absorption spectra were obtained with the diamond cell under various temperatures and pressures. From the splitting of the 725-735 cm⁻¹ CH rocking frequency band it was possible to infer crystallization at certain pressures and temperatures for the ester and the petroleum fluid. Entrance optics were built to convert the Fourier infrared interferometer into an emission micro-interferometer and it was possible to show the equivalence between absorption and emission spectra at the same temperature and pressure. This achievement constitutes a major breakthrough; for while infrared emission spectra of thin layers of organic material on metal substrates have been obtained by previous investigators, spectra from radiating areas as Hertzian contacts and at average temperatures as low as 30-50°C very nearly represent the limit of today's instrumental capability.

A model ball-on-plate apparatus was then built for the same interferometer and entrance optics. The window was located at the bottom of a cup containing the test fluid. A loaded bearing ball rotated about a horizontal axis while sliding over the window provided the bearing contact. The apparatus was located above the interferometer entrance optics. Precise alignment of the contact region on the optic axis and in the focal plane of the entrance optics was essential and was achieved.

The analysis of the spectra gave some surprising results. It was possible to deduce both ball surface and fluid film temperatures from the spectra. When temperature differences were plotted against shear rate, the data for all the fluids fell on practically the same curve, which showed a peak corresponding to an intermediate shear rate. The traction fluid reached the highest temperature difference under equal conditions. However, the polyphenyl ether would reach the highest absolute temperature at high shear rates -- just prior to bearing failure. At the same time its spectrum would change, indicating decomposition. Another observation was an intensity change with shear rate of one band, which could be related to polarization of the emitted radiation. The mechanism for it might well be streaming birefringence, although other explanations have not yet been excluded.

A separate but related achievement was the design and construction of apparatus to determine pressure and state of material in the diamond anvil cell from the peak frequency and width of the fluorescence band of ruby crystals contained within the sample. In contrast to earlier opinion considering traction as caused by glassy particles in the contact zone, the traction fluid tested needed higher pressures to be converted into the glassy state than the other fluids and must therefore function by a different mechanism.

[illegible]

COMPLETED PROJECT SUMMARY

1. TITLE: Infrared Spectra of Fluid Films under Conditions of Incipient Bearing Failure, Phase I.
2. PRINCIPAL INVESTIGATOR: Dr. James L. Lauer
Sun Oil Company
Applied Research and Development Department
P. O. Box 1135
Marcus Hook, PA 19061
3. INCLUSIVE DATES: 1 January 1974 - 30 June 1976
4. CONTRACT NUMBER: AFOSR-F44620-74-C-0038
5. COSTS AND FY SOURCE: \$20,000 (Government) + \$ 9,213 (Sun Oil Co.) FY 73;
\$40,000 (Government) + \$26,667 (Sun Oil Co.) FY 74;
\$44,992 (Government) + \$29,995 (Sun Oil Co.) FY 75;
6. SENIOR RESEARCH PERSONNEL: Dr. James L. Lauer
Mr. Melvin E. Peterkin
7. JUNIOR RESEARCH PERSONNEL: None
8. PUBLICATIONS:

"Infrared Emission Spectra of Liquids in a Diamond Anvil Cell by Interferometry," James L. Lauer and M. E. Peterkin, Applied Spectroscopy 29, 78 (1975).

"Infrared Emission Spectra of Liquids in a High Pressure Diamond Cell with the Beckman-RIIC FS-720 Interferometer," James L. Lauer and M. E. Peterkin, The Transform, No. 3, p. 22-25, (September 1974) (R.J. Jakobsen, Editor, Battelle Memorial Institute, 505 King Avenue, Columbus, Ohio 43201).

"Analysis of Infrared Spectra of Fluid Films in Simulated EHD Contacts," James L. Lauer and M. E. Peterkin, Lubrication Technology, Vol. 97, Series F, No. 2, p. 145-50 (April 1975).

"Study to Define Behavior of Liquid Lubricants in an Elastohydrodynamic Contact," James L. Lauer, NASA CR-134671, October 17, 1974. Prepared for National Aeronautics and Space Administration, NASA Lewis Research Center, Cleveland, Ohio. 95 Pages. \$3.00 (Unclassified).

"Infrared Emission Spectra of Liquids in a Diamond Anvil Cell by Interferometry," James L. Lauer and M. E. Peterkin, Applied Spectroscopy, 29, 78 (January 1975).

"Infrared Emission Spectra of Elastohydrodynamic Contacts," James L. Lauer and M. E. Peterkin, J. Lubrication Technology, 98, 230-235 (1976).

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"Infrared Emission Spectra of Fluid Films," James L. Lauer and M. E. Peterkin, American Laboratory, Vol. 7, No. 11, pp. 27-33 (November 1975).

"Analysis of Infrared Spectra of Elastohydrodynamic Lubricant Films," James L. Lauer and M. E. Peterkin, Petroleum Division Preprints, American Chemical Society National Centennial Meeting, Symposium on Lubricant Properties in Thin Lubricating Films, New York City, April 6, 1976, pp. 48-56.

"High Pressure Interferometry," James L. Lauer in "Fourier Transform IR: Applications to Chemical Systems", J.R. Ferraro and L. J. Basile, editors, to be published in the spring of 1977 by Academic Press, New York, 75 pp., figures and tables.

"Infrared Emission Spectra from Operating Elastohydrodynamic Sliding Contacts," James L. Lauer, NASA CR-134973, March 8, 1976. Prepared for National Aeronautics and Space Administration, NASA Lewis Research Center, Cleveland, Ohio. 87 Pages. \$3.00 (Unclassified).

"Traction and Lubricant Film Temperature as Related to the Glass Transition and Freezing," James L. Lauer and M. E. Peterkin, To be published in Can. J. of Spectroscopy 21, Sept./Oct. 1976.

"Traction and Lubricant Film Temperature as Related to the Glass Transition and Freezing," James L. Lauer and M. E. Peterkin, Lubrication, to be published in 1977.

9. ABSTRACT OF OBJECTIVES AND ACCOMPLISHMENTS

Under conditions of high stress moving parts of machinery, such as bearings or gears, are prevented from self-destruction by the interposition of extremely thin films of lubricants. Since failure is unlikely to occur without warning, examination of the lubricant in operating bearings approaching failure appeared to be a procedure promising to provide clues on reasons for failure and thus to provide a basis for improved lubrication. The method of analysis chosen was infrared emission Fourier spectrophotometry, a relatively new procedure which is particularly well adapted to thin film analysis and which -- in contrast to absorption spectrophotometry -- requires only one window transparent to infrared radiation. The fluid film heated by internal friction during bearing operation takes the place of the source for the spectrophotometer.

This phase of the work was (i) to demonstrate that infrared emission spectrophotometry can be applied to bearing contact situations, (ii) to provide background in the form of calibration spectra applicable to such situations, and (iii) to show the potential of the method in specific instances relevant to the failure problem. Very substantial obstacles had to be overcome: (i) very weak radiant power passed through the window and most of it originating from the solid boundary surfaces rather than from the lubricant film; (ii) different fluid and solid surface temperatures; (iii) ignorance regarding expected lubricant spectral changes with pressure, temperature, shear rate, and fluid/glass transition. Accordingly most of the effort involved the development of appropriate hardware and background information.

Bearing failure is most likely to occur when the solid surfaces bounding the lubricant are elastically deformed under so-called elastohydrodynamic (EHD) lubrication. Curved surfaces are then flattened over the "Hertzian" contact region. Furthermore, sliding is more severe than rolling, hence a loaded bearing ball rotating, i.e. sliding, on a plate was adapted as a model to represent a bearing nearing failure. By making the plate a diamond window, some heat generated in the contact can be transmitted as radiation for spectroscopic analysis. Since diamond is transparent throughout most of the infrared spectrum, the examination of spectral changes even in the "fingerprint" infrared region (10-15 μm) and in the lattice region ($>15\mu\text{m}$) is feasible. For calibration of the spectral information of the ball-on-plate apparatus a high-pressure diamond anvil cell was used as a "simulated contact". Its sample volume could be subjected to most of the conditions likely to prevail in a sliding EHD Hertzian contact (thickness $<2\mu\text{m}$, open area $\sim 0.25\text{ mm}^2$, pressures 0-75 kbar, temperatures 0-200°C) except for shear. As typical fluids, an ester, polyphenyl ether (5P4E), a standard petroleum lubricant, and a so-called "traction" fluid were used. A Fourier infrared interferometer was adapted for all the spectroscopic work.

In the initial stages of the program, absorption spectra were obtained with the diamond cell under various temperatures and pressures. From the splitting of the $725\text{--}735\text{ cm}^{-1}$ CH rocking frequency band it was possible to infer crystallization at certain pressures and temperatures for the ester and the petroleum fluid. Entrance optics were built to convert the Fourier infrared interferometer into an emission micro-interferometer and it was possible to show the equivalence between absorption and emission spectra at the same temperature and pressure. This achievement constitutes a major breakthrough; for while infrared emission spectra of thin layers of organic material on metal substrates have been obtained by previous investigators, spectra from radiating areas as small as Hertzian contacts and at average temperatures as low as 30-50°C very nearly represent the limit of today's instrumental capability.

A model ball-on-plate apparatus was then built for the same interferometer and entrance optics. The window was located at the bottom of a cup containing the test fluid. A loaded bearing ball rotated about a horizontal axis while sliding over the window provided the bearing contact. The apparatus was located above the interferometer entrance optics. Precise alignment of the contact region on the optic axis and in the focal plane of the entrance optics was essential and was achieved. Indeed it was possible to obtain "dynamic" infrared spectra from the fluids under various conditions prevailing in the Hertzian area.

The analysis of the spectra gave some surprising results. It was possible to deduce both ball surface and fluid film temperatures from the spectra. When temperature differences were plotted against shear rate, the data for all the fluids fell on practically the same curve, which showed a peak corresponding to an intermediate shear rate. The traction fluid reached the highest temperature difference under equal conditions. However, the polyphenyl ether would reach the highest absolute temperature at high shear rates -- just prior to bearing failure. At the same time its spectrum would change, indicating decomposition. Another observation was an intensity change with shear rate of one band which could be related to polarization of the emitted radiation. The mechanism for it might well be streaming birefringence, although other explanations have not yet been excluded.

A separate but related achievement was the design and construction of apparatus to determine pressure and state of material in the diamond anvil cell from the peak frequency and width of the fluorescence band of ruby crystals contained within the sample. In contrast to earlier opinion considering traction as caused by glassy particles in the contact zone, the traction fluid tested needed higher pressures to be converted into the glassy state than the other fluids and must therefore function by a different mechanism.

Work was started toward a reliable determination of the state of the fluid (liquid or glassy) from the dynamic infrared spectra.

AFOSR Program Manager: Lt. Col. Richard W. Haffner